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Summary

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The authors present the results of calculations of the fluxes of outgoing shortwave and longwave radiation at plane surfaces of various orientation located in the atmosphere at a height of 300 kilometers. The calculations are made for a given angular distribution of the intensity of the outgoing radiation. Conclusions are drawn concerning the possibility of using an isotropic approximation for computing the outgoing longwave radiation.

The question of the incidence of terrestrial radiation on variously oriented surfaces at a given level in the atmosphere is of great importance in connection with the problem of the heat balance of artificial earth satellites, the interpretation of measurements of the outgoing radiation made with the aid of meteorological satellites, and so on. As the authors have already shown [1], the fluxes of outgoing longwave radiation at variously oriented surfaces decrease fairly uniformly with increase in the angle of inclination of the surface. The work described in this article is based mainly on relative values of the radiation fluxes (relative to the flux through a horizontal surface). /443

Relative values of the outgoing longwave radiation fluxes F/F_h, computed from the angular distribution of the intensity of the outgoing radiation at the equator and at 65°N for a clear sky and continuous cloud with the top of the layers at heights of 3 and 9 km are indicated by circles in Fig. 1. An inspection of this figure shows that the dependence of the relative radiation fluxes on the angle of inclination is practically universal. The relative values, computed from the given angular intensity distribution of the outgoing radiation [1], are very close to the relative values computed in accordance with the "isotropic" approximation. Therefore, for approximate calculations of the relative fluxes of outgoing longwave radiation at differently oriented surfaces in the atmosphere this approximation may be employed. It should be noted, however, that it is still necessary to make an additional investigation of the case of partial cloud nonuniformly distributed in the horizontal direction.

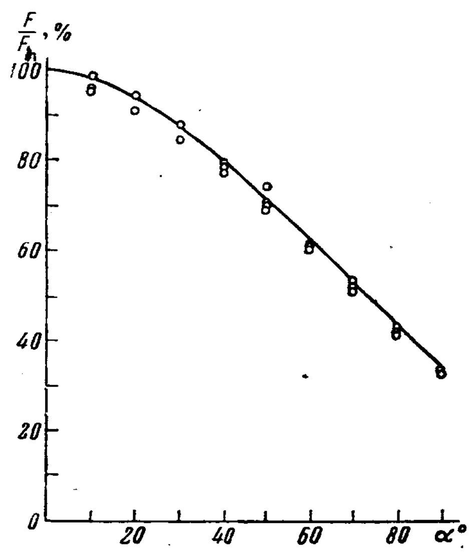

Fig. 1. Relative fluxes of outgoing longwave radiation as a function of angle of inclination of surface. Circles - F/F_h for the equator and 65°N for clear sky and continuous cloud. Solid curve - relative fluxes as a function of angle of inclination for outgoing radiation.

On the basis of calculations of the fluxes of outgoing long-wave radiation it is possible to estimate the angle at the vertex of the cone, within the limits of which 90% of the flux incident on a given surface is included. These calculations show that for all the chosen orientations of the surfaces this angle (or the so-called "effective zone") is roughly 60°. Only for surfaces with an angle of inclination $\alpha > 70°$ does the effective zone increase to 70°.

The effective zone, within the limits of which 50% of the outgoing longwave radiation is included, is roughly 30° for surfaces with an angle of inclination $\alpha < 70°$, and 45-50° for surfaces with an angle of inclination $\alpha > 70°$. /444

Let us now consider the results of computations of the fluxes of outgoing shortwave radiation at variously oriented surfaces.

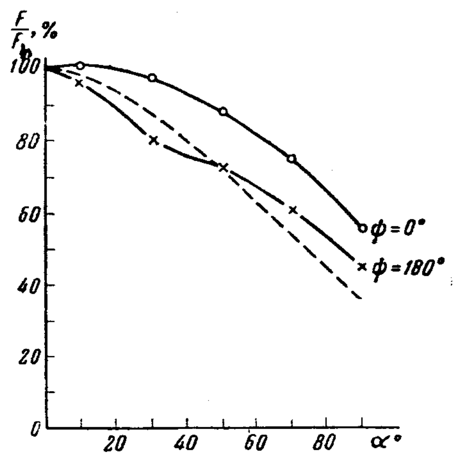

Fig. 2. Relative fluxes of outgoing shortwave radiation as a function of the angle of inclination of the surface for $z_{\odot} = 75°$, $\tau^* = 0.2$ and $q = 0.1$.

The shortwave fluxes were calculated from the angular intensity distribution of outgoing radiation obtained by theoretical means in [2].

Note that in [2] the angular intensity distribution for outgoing shortwave radiation was calculated for a plane-parallel, horizontally stratified atmosphere, at the top of which the sun's rays were incident in a parallel beam. It is assumed that the surface of the earth reflects the incident radiation in accordance with Lambert's law. The scattering coefficient and indicatrix are assumed to be given. Polarization of the light is neglected. The variation in the scattering function with height is taken into account very simply: the atmosphere is divided vertically into two layers, in each of which the indicatrix is assumed to be constant.

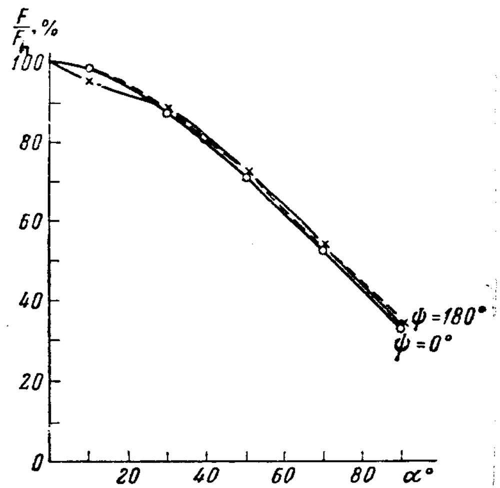

Fig. 3. Relative fluxes of outgoing shortwave radiation as a function of the angle of inclination of the surface for $z_{\odot} = 30°$, $\tau^* = 0.8$ and $q = 0.8$.

The angular intensity distribution of the outgoing shortwave radiation may be fairly complex, depending on the distribution of cloud over the area in question, the albedo of the surface, and the conditions of exposure of the surface to direct solar radiation. The calculations of the intensity of the outgoing shortwave radiation, made in [2] for a completely exposed surface with uniform albedo, showed that for small zenith angles of the sighting point (up to 45°)

the outgoing radiation intensities for real and isotropic scattering are similar in magnitude at all azimuths. At large zenith angles the radiation intensities are significantly different, the difference increasing with decrease in the azimuth of the point in question (azimuth reckoned from the direction of the sun). It is necessary to emphasize that these results were obtained for a plane-parallel atmosphere and very simple optical conditions. Thus, it may be assumed that under real conditions the field of outgoing shortwave radiation may be essentially nonisotropic.

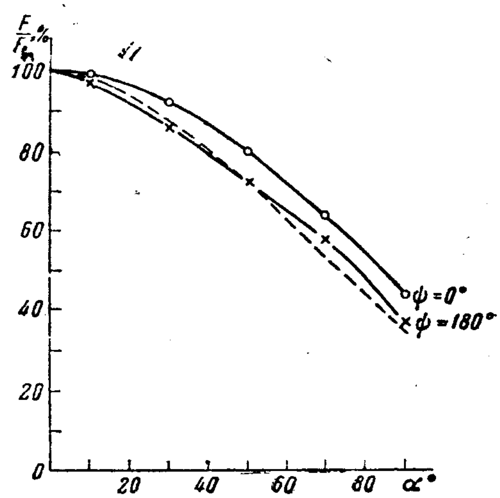

Fig. 4. Relative fluxes of outgoing shortwave radiation as a function of the angle of inclination of the surface for $z_{\odot} = 75°$, $\tau^* = 0.8$ and $q = 0.8$.

Accordingly, accurate values of the fluxes of outgoing shortwave radiation at differently oriented surfaces may be calculated only by numerical integration with respect to a given angular intensity distribution of the outgoing radiation.

TABLE 1

Fluxes of outgoing shortwave radiation (in relative units) at plane surfaces of various orientation; $\tau^* = 0.8$, $q = 0.1$

α, °	$z_\odot$, °								F/F_h for isotropic radiation, %
	30				75				
	ψ, °								
	0		180		0		180		
	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	
0	1.117	100	1.117	100	0.570	100	0.570	100	100
10	1.077	96.4	1.083	97	0.546	95.8	0.547	96.1	98.5
30	0.963	86.2	0.952	85.3	0.544	95.6	0.484	85	87.8
50	0.816	73	0.901	80.6	0.494	86.8	0.418	73.4	72
70	0.625	56	0.698	62.5	0.416	73.1	0.361	63.4	53.8
90	0.413	37	0.437	39.1	0.307	54	0.239	41.9	35.2

TABLE 2

Fluxes of outgoing shortwave radiation (in relative units) at plane surfaces of various orientation; $\tau^* = 0.2$, $q = 0.8$

α, °	$z_\odot$, °								F/F_h for isotropic radiation, %
	30				75				
	ψ, °								
	0		180		0		180		
	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	
0	3.733	100	3.733	100	1.127	100	1.127	100	100
10	3.874	103.8	3.880	103.9	1.118	99.2	1.102	97.8	98.5
30	3.461	92.7	3.480	93.2	1.019	90.4	0.984	87.4	87.8
50	2.847	76.3	2.768	74.2	0.864	76.7	0.823	73	72
70	2.130	57	2.156	57.8	0.675	59.9	0.631	56	53.8
90	1.339	35.9	1.358	36.4	0.453	40.2	0.411	36.4	35.2

TABLE 3

Fluxes of outgoing shortwave radiation (in relative units) at plane surfaces of various orientation; $\tau^* = 0.4$, $q = 0.3$

α, °	$z_\odot$, °												F/F_h for isotropic radiation, %
	30						60						
	ψ, °												
	0		90		180		0		90		180		
	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	F	F/F_h, %	
0	1.656	100	1.656	100	1.656	100	1.055	100	1.055	100	1.055	100	100
10	1.626	98.2	1.631	98.5	1.636	98.8	1.042	98.7	1.039	98.5	1.037	98.2	98.5
30	1.448	87.4	1.646	88.4	1.482	89.4	0.945	89.5	0.936	88.6	0.936	88.6	87.8
50	1.308	78.9	1.214	73.3	1.240	74.9	0.805	76.3	0.785	74.4	0.795	75.3	72
70	1.109	67	0.917	55.3	1.051	63.4	0.633	60	0.601	57	0.621	58.8	53.8
90	0.577	34.8	0.582	35.2	0.610	36.8	0.429	40.7	0.388	36.7	0.414	39.3	35.2

We have calculated the fluxes of outgoing shortwave radiation at variously oriented surfaces at a height of 300 km. The calculations were made in accordance with the method described in [1]. /446

All the computations in [2] were made in relative units. Since we are investigating the variability of the distribution of the outgoing radiation fluxes at inclined surfaces as a function of their orientation and the fluxes at the inclined surfaces are compared with those at a horizontal surface, the values of the fluxes may also be expressed in relative units.

The fluxes of outgoing shortwave radiation were computed for surfaces with an angle of inclination with respect to the horizontal plane $\alpha = 0$, 10, 30, 50, 70 and 90°, oriented along the azimuth $\psi = 0$, 90 and 180° relative to the direction of the sun and for the following values of the optical parameters: optical thickness of entire atmosphere $\tau^* = 0.2$, 0.4 and 0.8; solar zenith distance $z_\odot = 30$, 60 and 75°; and surface albedo $q = 0.1$, 0.3 and 0.8. The results of the computations are presented in Tables 1-3.

An analysis of the data obtained shows that the variability of the fluxes of outgoing shortwave radiation as a function of the angle of inclination of the surface is roughly the same as in the case of longwave radiation fluxes (cf. [1]). The outgoing radiation fluxes (expressed in relative units) vary significantly as a function of the solar zenith distance, the optical thickness of the atmosphere, and the surface albedo. A comparison of the values for the outgoing radiation fluxes revealed that at small albedos ($q = 0.1$) for a given solar zenith distance the fluxes of outgoing radiation at plane surfaces with different orientation increase with increase in the optical thickness of the atmosphere. At high albedos ($q = 0.8$) the fluxes of outgoing shortwave radiation decrease with increase in the optical thickness of the atmosphere, given a constant solar zenith angle. Clearly, these results are attributable to the effect of atmospheric haze, which increases the albedo of the system surface-atmosphere when the surface has a low albedo and reduces it when the /447 surface has a high albedo. For constant values of τ^* and $z_\odot$ the fluxes of outgoing shortwave radiation increase by 3-5 times with increase in the surface albedo from 0.1 to 0.8.

The dependence of the relative shortwave radiation fluxes (relative to the flux at a horizontal surface) F/F_h on the steepness and azimuth of the surface is presented graphically in Figs. 2-4. The broken-line curve was calculated for relative values of the isotropic shortwave radiation fluxes. It is clear from the figure that for high values of the albedo the relative values of the radiation fluxes, calculated from the angular distribution of the intensity of the outgoing shortwave radiation, differ comparatively little from the corresponding values computed for an isotropic radiation field. Noteworthy differences are observed at low values of the albedo (Fig. 2, $q = 0.1$) and at high solar zenith distances. This is connected with the fact that, as noted in [2], with decrease in the surface albedo there is an increase in the effect of nonisotropic scattering.

The relative values of the fluxes of outgoing shortwave radiation for small solar zenith distances ($z_{\odot} = 30°$) prove to be fairly close for different combinations of the optical characteristics τ^* and q.

The dependence of the relative fluxes on the azimuth is inconsiderable at small, but more appreciable at large solar zenith distances.

Thus, we may assume that for the simple atmospheric conditions selected in many cases the angular dependence of the relative values of the outgoing shortwave radiation fluxes is practically the same and closely corresponds to the dependence for the case of an isotropic radiation field.

In more complex optical situations, when the area of the surface within the field of view of the instrument is partially illuminated by the sun, and for conditions of partial cloud, the outgoing radiation fluxes must be determined for each individual case. Therefore, in the future it will be necessary to calculate the outgoing radiation fluxes for more complex cases and conditions of partial cloud with the object of obtaining sufficient material for a statistical analysis.

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